field at temperatures above the hydrate formation level from 32°F. to about 80°F and at pressures of from about 200 to about 2500 psig. This patent makes no mention of a salt cavern. This patent makes no mention of dense phase or the importance thereof. Furthermore, there are limitations on the injection and send our capacity of depleted and partially depleted gas reservoirs that are not present in salt cavern storage. In addition, temperature variances between the depleted reservoir and the injected gas create problems in the depleted reservoir itself that are not present in salt cavern storage. For all of these many reasons, salt caverns are preferred over cryogenic storage tanks or depleted gas reservoirs for use in a modern LNG facility.

SUMMARY OF INVENTION

[0019] The Bishop One-Step Process warms a cold fluid using a heat exchanger mounted onshore or a heat exchanger mounted offshore on a platform or subsea and stores the resulting DPNG in an uncompensated salt cavern. In an alternative embodiment, a conventional LNG vaporizer system can also be used to gasify a cold fluid prior to storage in an uncompensated salt cavern or transmission through a pipeline.

[0020] The term "cold fluid" as used herein means liquid natural gas (LNG), liquid petroleum gas (LPG), liquid hydrogen, liquid helium, liquid olefins, liquid propane, liquid butane, chilled compressed natural gas and other fluids that are maintained at sub-zero temperatures so they can be transported as a liquid rather than as gases. The heat exchangers of the present invention use a warm fluid to raise the temperature of the cold fluid. This warm fluid

used in the heat exchangers will hereinafter be referred to as warmant. Warmant can be fresh water or seawater. Other warmants from industrial processes may be used where it is desired to cool a liquid used in such a process.

[0021] To accomplish heat exchange in a horizontal flow configuration, such as the Bishop One-Step Process, it is important that the cold fluid be at a temperature and pressure such that it is maintained in the dense or critical phase so that no phase change takes place in the cold fluid during its warming to the desired temperature. This eliminates problems associated with two-phase flow such as stratification, cavitation and vapor lock.

[0022] The dense or critical phase is defined as the state of a fluid when it is outside the two-phase envelope of the pressure-temperature phase diagram for the fluid (see Fig. 9). In this condition, there is no distinction between liquid and gas, and density changes on warming are gradual with no change in phase. This allows the heat exchanger of the Bishop One-Step Process to reduce or avoid stratification, cavitation and vapor lock, which are problems with two-phase gas-liquid flows.

BRIEF DESCRIPTION OF DRAWINGS

[0023] Fig. 1 is a schematic view of the apparatus used in the Bishop One-Step Process including a dockside heat exchanger, salt caverns and a pipeline.

[0024] Fig. 2 is an enlarged section view of the heat exchanger of Fig. 1. The flow arrows indicate a parallel flow path. Surface reservoirs or ponds are used to store the warmant.

cryogenic tanks that are on board the cold fluid transport ship. The Bishop One-Step Process does not require cryogenic storage tanks as a part of the onshore facility.

[0088] Recognizing some of these performance problems with open rack vaporizers, Osake Gas has developed a new vaporizer called the SUPERORV, which uses seawater as the warmant. Drawings of the SUPERORV and conventional open rack vaporizers are shown on the Osaka Gas web site (www.osakagas.co.jp). The distinctions listed above between the heat exchanger used in the Bishop One-Step Process are likewise believed to be applicable to the SUPERORV.

[0089] Fig. 6 is a section view of the first section of the heat exchanger along the line 6-6 of Fig. 2. (Fig. 6 is not drawn to scale.) The coaxial heat exchanger 62 includes a center pipe 61 formed of material suitable for low temperature and high-pressure service, while the outer conduit 104 may be a material not suited for this service. This allows the outer conduit 104 to be formed from plastic, fiberglass or some other material that may be highly corrosion or fouling resistant, as it needs to be in order to transport the warmant 99 such as fresh water 19 or sea water 20. The annular area 101 between the outside diameter of the central pipe 61 and the inside diameter of the outer conduit 104 may need to be treated chemically periodically for fouling. The center pipe 61 will typically have corrosion resistant properties.

[0090] The center pipe 61 will be equipped with conventional centralizers 108 to keep it centered in the outer conduit 104. This serves two functions. Centralizing allows the warming to be uniform and thus minimize the

occurrence of cold spots and stresses. Perhaps more importantly, the supported, centralized position allows the inner pipe 61 to expand and contract with large changes in temperature. The centralizer 108 has a hub 107 that surrounds the pipe 61 and a plurality of legs 109 that contact the inside surface of the outer conduit 104. The legs 109 are not permanently attached to the outer conduit 104 and permit independent movement of the inner pipe 61 and the outer conduit 104. This freedom of movement is important in the operation of the invention. To further permit expansion and contraction in the surface mounted heat exchanger 62 of Fig. 1, the outlet 63 is connected to a flexible joint 65 which also connects to non-cryogenically compatible piping 70. Likewise in subsea heat exchanger 220 of Figs. 4 and 5, the outlet 236 is connected to a flexible joint 238 which also connects to non-cryogenically compatible piping 240. All of the centralizers that are used in this invention should allow movement (expansion, contraction and elongation) of the cryogenically compatible inner pipe independent of the outer conduit without causing significant abrasion and unnecessary wear on either. The cold fluid 51 passing through the cryogenically compatible piping is cross-hatched in Figures 6, 7 and 8 for clarity.

[0091] Fig. 7 is a section view of an alternative embodiment of the heat exchanger used in the Bishop One-Step Process. In the alternative embodiment of Fig. 7, a central cryogenically compatible pipe 300 is centered inside of an intermediate cryogenically compatible pipe 302 by centralizers 304. The intermediate pipe 302 is centered inside the outer conduit 104 by centralizers 305. The centralizer 305 has a centralizer hub 302, which is held in place by a plurality of legs 306. An annular area 308 is defined between the outside diameter of the intermediate pipe 302 and the inside diameter of

the outer conduit 104. Warmant 99 passes through the annular area 308. The legs 306 are not permanently attached to the inside of the outer conduit 104 to allow the cryogenically compatible pipes to expand and contract independent of the outer conduit 104. Warmant 99 also passes through the central pipe 300. The cold fluid 51 passes through the annular area 309 between the outside diameter of the central pipe 300 and the inside diameter of the centralizer hub 302. The cold fluid 51 in the annular area 309 is crosshatched in Fig. 7 for clarity. The alternative design of Fig. 7 has a greater heat exchange area and therefore the length of a heat exchanger using the alternative design of Fig. 7 may be shorter than the design in Fig. 6. In those circumstances where a relatively short heat exchanger may be preferable, the alternative design of Fig. 7 may be more suitable than the design of Fig. 6. In some circumstances, it may be necessary to develop even a shorter heat exchanger.

[0092] Fig. 8 is a section view of a second alternative embodiment of the heat exchanger used in the Bishop One-Step Process. Interior cryogenically compatible pipes 320, 322, 324 and 326 are held in a bundle and are centered inside the outer conduit 104 by a plurality of centralizers 327. The centralizers 327 have centralizer hubs 328. The interior pipes 320, 322, 324 and 326 are cross-hatched to indicate that they carry the cold fluid 51. The centralizer hub 328 is positioned in the middle of the outer conduit 104 by legs 330, which are not permanently attached to the outer conduit 104. Warmant 99 passes through the annular area 334. The alternative embodiment of Fig. 8 should allow for even a shorter length heat exchanger than the design show in Fig. 7. When space is at a premium, alternative designs such as Fig. 7 and Fig. 8 may be suitable and other designs may

also be utilized that increase the area of heat interface.

[0093] Fig. 9 is a temperature-pressure phase diagram for natural gas. Natural gas is a mixture of low molecular weight hydrocarbons. Its composition is approximately 85% methane, 10% ethane, and the balance being made up primarily of propane, butane and nitrogen. In flow situations where conditions are such that gas and liquid phases may coexist, pump, piping and heat transfer problems, discussed below, may be severe. This is especially true where the flow departs from the vertical. In downward vertical flow such as shown in U.S. Patent No. 5,511,905, the liquid velocity must only exceed the rise velocity of any created gas phase in order to maintain uninterrupted flow. In cases approaching horizontal flow with a two-phase fluid, the gas can stratify, preventing the heat exchange, and in extreme cases causing vapor lock. Cavitation can also be a problem.

[0094] In the present invention, these problems are avoided by insuring that the cold fluid 51 is converted by the high-pressure pump system 56 or 230 into a dense phase fluid 64 and that it is maintained in the dense phase while a) it passes through the heat exchanger 62 or 220 and b) when it is stored in an uncompensated salt cavern. The dense phase exists when the temperature and pressure are high enough such that separate phases cannot exist. In a pure substance, for which this invention also applies, this is known at the critical point. In a mixture, such as natural gas, the dense phase exists over a wide range of conditions. In Fig. 9, the dense phase will exist as long as the fluid conditions of temperature and pressure lie outside the two-phase envelope (cross-hatched in the drawing). This invention makes use of the dense phase characteristic so there is no change in phase with increase in